that eleventh group and their group of Carnivora. It has been often suggested that the Bears are the nearest existing allies of the Seals. There is, however, little in the anatomy of the true Seals to force conviction on us as to this matter; but when we turn to the brain of *Otaria*, we may, I think, therein read a very striking confirmation of the suggestion. The Arctoid group, and the Arctoid group alone of all Carnivora, possesses an "Ursine lozenge." That striking and exceptional feature is plainly to be seen (as herein pointed out) in the brain of *Otaria*. This circumstance, I venture to think, makes it very highly probable that the ancestor of the Pinnipedia was an Arctoid animal not very remote from the Ursine group of that extensive suborder.

In conclusion I desire to express my thanks to the authorities of the Royal College of Surgeons for the great facilities afforded me in studying the subject, and for their kindness in permitting drawings to be made from the specimens therein preserved.

On the Family *Arbaciadæ*, Gray.—Part I. The Morphology of the Test in the Genera *Cœlopleurus* and *Arbacia*.

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[Read 5th February, 1885.]

(Plates I. & II.)

Contents.

I. *Introduction.*

The Arbaciadæ of Gray, or the Echinocidaridæ of Desmoulins, have been studied, more or less, by nearly every naturalist who has investigated or classified the Echinoidea.

The embryology of species of the genus which gives the name to the family has been studied by A. Agassiz, Selenka, Busch,

Fewkes, Garman, and Colton; and every one of us who is interested in the subject, will remember that a species was traced during the stages of its early growth, from the Pluteus to the young perfect form, by Johannes Müller, the father of this kind of research, in 1855.

The classificatory studies of the family, the descriptions of the species, and the arguments regarding the affinities of the forms, and the necessary limitation of the family to certain genera, have occupied the attention of especially Desmoulins, Gray, Desor, E. Forbes, Blainville, L. Agassiz, Aradas, Sars, Delle Chiaje, Verrill, A. Agassiz, Lütken, and Troschel. We owe some important morphological studies to Lovén, and also to A. Agassiz and Troschel.

The 'Revision of the Echini' by A. Agassiz contains, besides the synonymy of the species of the genera of the family, the history of the successive writings on the group, and the arguments regarding the propriety of extending the family so as to include the genera *Cœlopleurus* and *Podocidaris*, and also very careful descriptions and drawings of the more important parts of the species.

The value of these researches by A. Agassiz is enhanced by his subsequent writings in the Report on the Echinoidea of the 'Challenger' Expedition, and in his Report on the dredgings of the U. S. Steamer 'Blake.' The delineations of *Arbacia nigra* (Molina, sp.) by Lovén in his 'Études sur les Échinoïdées,' and those of the species of *Arbacia*, *Cœlopleurus*, and *Podocidaris* by A. Agassiz, leave little to be desired.

In 1883 we were describing the Tertiary Echinoidea of Kachh and Kattywar for the 'Palæontologia Indica,' and we had the opportunity of studying excellent specimens of species from two geological horizons, namely the Oligocene and Miocene. Subsequently we extended our work, and have completed the description of the Echinoidea of Sind.

We have thus been enabled to study several points in the morphology of the test of four species of *Cœlopleurus*; and the result led us to examine the recent species of *Cœlopleurus* from the seas to the east of Africa. Owing to the kindness of Dr. Günther, F.R.S., we have been enabled to examine the specimens of *Cœlopleurus Maillardi*, A. Agassiz, in the National Collection, and to compare their structures with those of the fossil forms.

Pursuing our investigations, we studied the test of the species

of *Arbacia* in the National Collection, with the assistance of some specimens belonging to us; and it has resulted that we can offer to those students of the Echinoidea who are interested in this family, some descriptions of new morphological details which must affect the classification.

The communication which we bring before the Society consists of two parts. In the first, the nature of the structures of the ambulacra, of the interradial plates, and of the radial plates in the fossil and recent *Cœlopleuri* and in the species of *Arbacia* are considered. In the second part we shall consider the classification of the family.

We use the name *Arbacia* because Gray, in our opinion, has the precedence over Desmoulins, whose name *Echinocidaris* is, however, much the better of the two.

Genus Cœlopleurus, *L. Agassiz.*

II. *The Fossil Species of* Cœlopleurus, *L. Ag.**

The Ambulacra.—The species which were examined were *C. equis*, Ag., *C. Pratti*, d'Archiac, *C. Forbesi*, d'Archiac, and *C. sindensis*, nobis †.

The ambulacra of the species of *Cœlopleurus* which are found fossil may, for the purpose of description, be divided into three regions—the region of the ambitus, that of the peristome, and the apical region. The arrangement of the plates differs in each of these divisions; but it is evident that in the fossil forms, as in the recent, the plates of the aboral region were the last formed, the peristomial are the oldest, and the plates of the ambitus are of an intermediate age. It is also evident that, in common with other Echinoidea with multiple or combined plates, the *Cœlopleuri* present the simplest plates in the aboral region of the ambulacra and the most complicated in the peristomial portions, but the complication is very slight there in the genus now under consideration.

All the fossil species of the genus *Cœlopleurus* from the Oligo-

* The literature of the Arbaciadæ is carefully given in the 'Revision of the Echini' by Alex. Agassiz, and we may add two references of work which relates to that we now describe:—Lovén, 'Études sur les Échinoïdées,' Stockholm, 1874; Troschel, Archiv für Naturgeschichte, Wiegmann, 1872, p. 293, and 1873, p. 308.

† "Fossil Echinoidea of Sind:" Nari and Gáj Series, 1884–1885; "Fossil Echinoidea of Kachh and Kattywar," 1883: see 'Palæontologia Indica,' Series XIV. (Duncan and Sladen).

cene and Miocene of Sind and Kachh are characterized by the great development of the ambulacra, their tumidity, the presence of great primary tubercles in them, decreasing in size towards the peristome and the apical region, and the presence of triple pairs of pores around the great tubercles.

The arrangement of the three plates which form a compound and tubercle-bearing plate, in so many genera, has been described in many works on the Echinoidea, and illustrated by almost every writer on the subject. Take, for example, a plate with three pairs of pores in the young form of a species of *Strongylocentrotus*, as drawn by Lovén * (Pl. I. fig. 1).

The plate is seen to be traversed by the imperfectly united sutural edges of three plates, of which the middle one is small and does not reach far into the united plate. The two others are large, and they both and their uniting suture reach the inner or median line of the ambulacrum.

The two large plates, a' & a'', are called primary, because they reach from the outer to the inner edge of the multiple plate, and thus are comparable with true primary plates which are separate, and reach from the interradium to the median line of the ambulacrum.

The small plate, b, which fits in between the two primaries close to the interradial edge of the compound plate is called a demi-plate. The junction of the edges of the large plates, beyond the inner angle of the little demi-plate, is long, simple, and directed inwards towards the inner margin of the multiple plate and also upwards.

This line of united suture-edges is oblique in its direction, and therefore one of the large or primary plates must be larger than the other. In the example of the young *Strongylocentrotus* it is, as is usual, the lower or adoral primary which is the largest, and because the direction of the upper edge of it is inwards and upwards. When there is a tubercle on the multiple plate, the line of the junction of the upper and lower primary plates crosses it.

The line may cross the boss, or the mamelon, or the space between the top of the boss and the mamelon, and usually the inner end of the demi-plate separates the long line of junction of the others, on the shoulder of the tubercle.

The study of the ambulacral plates close to the radial plate shows that, however complicated they may be lower down in the

* 'Études,' Plate xvii. fig. 140.

test, they are simple and primary when first produced, and that as there is a gradual growth of plates from the radial-plate end towards the peristome during the whole life of the individual, the increasing pressure from above downwards, or aborally adorally, produces absorption of, or interferes with the growth of, the inner parts of some plates and develops the demi-plate.

The demi-plate intercalated between the large primaries in a compound or multiple plate, is not an independent or superadded structure, but a modification of a primary plate during the growth of the ambulacrum as a whole.

Lovén has shown, in his 'Études,' pp. 23, 24, that even the apparently confused doubling and trebling of the arcs of the pairs of pores near the peristome in some adult Echini, is not due to the development of new pore-bearing plates, but to a downward movement and diminution of the height and breadth of the original plates accompanied by a movement of the pairs of pores, especially of those in the larger plates of the compound plates. There is no real confusion, for the pairs of pores assume their places in a regular order.

Cœlopleurus. Region of the Ambitus.—If a large tubercle-bearing plate of an ambulacrum of one of the species of *Cœlopleurus* already named be carefully examined, there is no difficulty in deciding that it is really a multiple or compound plate, and that the arrangement of the three plates which compose it is totally different from that as yet observed in any other genus. Before describing the three plates, it is necessary to remark that the tubercle has a large flat edge to its base, which comes so close to the poriferous zone that the inner pores of the pairs of the triplet intrude on it, and as it were slightly erode it. The tubercle is large, covers nearly all the rest of the plate, and slopes up to a circular groove which is at the narrow base of a mamelon which is very small in relation to the size of the boss beneath. In some instances the base of the tubercle is not thus intruded upon (Pl. I. fig. 3).

On examining the three plates of this compound and tubercle-bearing plate, it is found that there is only one primary (*a*), and on the other hand there are two demi-plates (*b'*, *b''*). Moreover the upper or aboral plate and the lower or adoral plate of the compound plate are demi-plates, the large single primary being between them and extending far beyond them towards the inner edge of the plate at the median line.

The demi-plates are small and the primary is very large.

The demi-plates form a small part of the aboral and adoral mass of the boss, and the primary plate forms part of the outer or interradial side of the boss, the whole of the mamelon, and the whole of the inner half of the tubercle towards the median line of the ambulacrum (Pl. I. figs. 2 & 3).

The part of the tubercle-bearing plate between the mamelon and the median or vertical suture is free from any suture or sutures, and none cross it after the fashion of typical Triplechinidæ. The sutures of the demi-plates never come in contact, and therefore the inner part of the compound plate is not divided into two portions, and only one plate, the central of the triplet, reaches the line of the median suture of the ambulacrum.

The Aboral Demi-plate.—This is rather large for a demi-plate, and is about one third of the whole height of the compound plate in vertical measurement, that is to say near the interradial edge; further in, and on the shoulder of the boss of the tubercle, the height is about one sixth more. The breadth of the plate is about one half of that of the entire compound plate, but it may be a little more or less (Pl. I. figs. 2, 3). The edge of the demi-plate in contact with the interradium is low and curved, with the convexity outwards, and the opposite or inner edge is the longest in vertical measurement, and is situated upon the aboral slope of the boss. It there forms a rounded angle, usually rather acute in large tubercles. The angle is situated at the groove on the summit of the boss, and below the mamelon.

The direction and relative position of the edges or sutures of this plate are very singular. The adoral suture is entirely in contact with the abactinal edge of the outer or poriferous part of the large primary plate. This adoral suture commences at the interradial edge of its plate, and passes inwards and slightly adorally, to the adoral pore. Thence it is directed still slightly adorally and inwards up the tubercle towards the groove at the base of the mamelon; it then becomes curved, turns at an angle directly towards the apical or aboral transverse suture of the compound plate, and reaches it in one of three places, according to the position of the compound plate in the ambulacrum. The line of this ascending suture of the aboral demi-plate may be upwards and outwards, so as to reach the transverse suture, just alluded to, at the position of the adoral pore of the pair of pores which belong to the compound plate immediately above

(Pl. I. fig. 4); or it may be directly upwards, so as to make a right angle with the transverse suture at its junction (fig. 7); or, as is the most usual in the very large plates, the line is upwards and slightly outwards so as to reach the transverse suture nearer the pore than in the last instance.

The Adoral Demi-plate.—This plate resembles the aboral one reversed. It bounds the central primary plate adorally, as far as the lower side of the mamelon, and this structure separates it from the aboral demi-plate. The upper suture of the adoral demi-plate commences at the interradial edge, and passes inwards and slightly aborally to reach the adoral pore of the pair belonging to the primary just above; thence the line of the suture is still inwards and abactinally until the groove of the mamelon is reached immediately actinally to the mamelon. From that spot the inner suture of the demi-plate is bent and directed actinally, and either directly so as to meet the transverse suture of the compound plate (the adoral transverse suture), or obliquely so as to pass to the adoral pore of the demi-plate. In some tubercles an intermediate path is taken, and the line of suture reaches the transverse suture of the compound plate between the adoral pore and the spot situated vertically below the mamelon. The adoral suture of the demi-plate forms the outer or interradial half of the actinal transverse suture of the compound or tubercle-bearing plate.

The Central or Primary Plate.—This plate is the only one of the triple combination which reaches the median ambulacral suture. In shape and size this primary differs entirely from the demi-plate above and below it. For the purpose of facilitating the description of the plate, it may be divided into a low, broad, pore-bearing, outer part, and a very large inner and expanded portion. The first-mentioned part has a curved edge in contact with the interradium, and it is highest there; but further inwards and up the slope of the tubercle, the plate becomes low from above downwards, in consequence of the approach of the two demi-plates to the adoral and the aboral base of the mamelon. Nipped in as is the primary at this spot, still it embraces the whole of the mamelon and also much of the groove around it. This part of the plate forms the most outwardly projecting part of the compound plate, and its pair of pores is placed slightly externally to those of the demi-plates. The remaining part of the plate is the inner or expanded portion which spreads out,

occupies the inner half of the tubercle and of the compound plate, and comes to the inner or median suture of the triple plate. This part is limited aborally and adorally by the transverse sutures common to its plate and the compound plates which are placed immediately above and below.

The Ambulacra near the Peristome.—The tubercle-bearing or compound triple plates become smaller, lower, and narrower towards the peristome, and quite at the margin there is some turning in of the first plate in each zone, and a broad concavity at the ambulacral median line. On either side of the ambulacra is a small branchial cut, and a tall tag which is broad at the margin and long vertically; the latter is partly on an interradium and partly on an ambulacrum, and the cut is a shallow groove without ornamentation.

As the shape of the triple compound plates is lower near the peristome, the two demi-plates and the intermediate primary occupy less vertical space; the pairs of pores are also closer together (Pl. I. fig. 7).

The diminution of the breadth of the triple plate is accompanied by an inward passage, that is towards the median line, of the pairs of pores and also of the now small tubercles. The tubercles close in, as it were, towards the median line, and the closing in of the pairs of pores upon them is accompanied by an alteration in the shape of the demi-plates. They become nearly rectangular in shape, and the angles of their inner sutures are right angles; the direction of these sutures is vertical, and those which are in contact with the poriferous part of the central primary are nearly transverse, and not on the slant as they are higher up.

It was noticed that the pairs of pores are oblique on the edge of the large tubercles; now this obliquity increases in the pairs as they approach the peristome, and the adoral pores have the aboral nearly vertically above them, there being a slight trend externally (Pl. I. fig. 10). The amount of obliquity varies, but it is always decided. Close to the margin, the original first pair of pores usually has its adoral pore as a mere indentation, and it may happen that the third pair is on an oblique line with the second and somewhat pressed out of the order; but there is never any formation of secondary arcs of pairs of pores. The marginal pores are very small and close. The pairs are remote from the interradial edges of their plates which are on the area of the tag.

The Pits along the Median Suture.—As many as five deep pits may be seen in some species of *Cœlopleurus* along the median line of the ambulacra at the spots where the transverse sutures between the consecutive compound plates unite at the median line with the corresponding angular process of the neighbouring plate of the other zone (Pl. I. fig. 7). The first pit is close above the concave margin of the ambulacrum at the peristome, being separated from it by a narrow ridge, or it may be at the margin and even turned slightly inwards.

The pits form a zigzag up the median suture, and it is evident that each one was arched above and that it had a flat broad base.

The sutures may sometimes be seen passing along the hollowed-out deeply-seated surface.

The growth of the test was attended with a downward movement of the whole of the peristomial part, as well as of the other parts of the ambulacra, accompanied, apparently, by absorption of the oldest tubercles, pores, and pits.

The Ambulacra near the Radial Plates.—This part of an ambulacrum extends from the radial plate to the first large tubercle-bearing compound plate. It is narrow in comparison with the interradia on either side and with the part of the ambulacrum at the ambitus; but the poriferous zones are straight and the pairs of pores are increasingly wide apart and the pores are very large, except close to the radial plate (Pl. I. figs. 4 and 5). The pairs are not so distant as are the pores of the same pair, and the direction of the pores of each pair is oblique from within, outwards and upwards. The part of the plates between the pores of each pair is broad, and it is sometimes larger in this region than in that of the great tubercles.

The interporiferous areas are crowded with plates of very diverse shapes and dimensions, so as to resemble a broken and confused mosaic. The apparently disorderly arrangement is greatest midway between the radial plate and the first great tubercle, and great and little plates, some with, and others without, small tubercles, are jumbled together as if there were not room for them all. Some of the plates are largest at their poriferous part; others are larger, and their interporiferous expansion extends far over the median line and also adorally and aborally, so as to exclude the plates immediately above and below from the median line. Or the expansion may not be so great, and there may be some plates which reach the median line in succession, but

which are not great in vertical measurement like those just noticed, but low and yet broad. The arrangement of plates differs in the two zones of the ambulacra, as might be expected; and there is an indefinite alternation of large and small plates in the zones. The large plates are ornamented with small tubercles or with large granules according to the species; but although the tubercles seem to be on alternate plates first in one zone and then in the other, the examination of the weathered surfaces of most specimens shows clearly that there are plates intercalated which destroy this simple and superficial arrangement. It is true that at the ambitus the great plates which carry the tubercles, alternate in the zones: but that is evidently because the full development of the triple-plate combination has occurred. In the region now under consideration, the arrangement in perfect triplets is only foreshadowed. Really there is a method in the apparent confusion of the interporiferous parts of the ambulacral plates.

In the compound plates of the parts of the ambulacra already considered, there are two demi-plates and a large primary; and in the radial region primary plates, alone, exist close to the radial plate; then follow small primaries which are, as it were, kept from growing by the presence of the expanded and future tubercle-bearing parts of other primaries close by, and then a demi-plate is seen here and there. The demi-plate is seen crushed in between two larger plates, and sometimes there are two demi-plates in succession with a large expanded plate close above or below. The poriferous parts of the plates are only exposed to a pressure which is tolerably equal in one direction, and therefore any difference in size relates to symmetrical growth. In the interporiferous areas the growth is most irregular in consequence of the varying size of the plates; and the result is irregular pressure and the prevention of any increase in size of some plates, and their crushing and crowding out and away from the median line. As already mentioned, the ambulacral plates near the radial plate and for some distance down, are small primaries, and every one reaches the median line; but immediately that one of these begins to expand in its interporiferous part, a corresponding want of room is felt by the small primary immediately above, and which is bound to move adorally as others are added above, as well as to endeavour to increase circumferentially. Moving downwards, not increasing in expansion in a zone which increases in breadth, it follows that the small primary becomes a mere appendage to a

poriferous part, does not extend to the median line, becomes a demi-plate, and rests against a large plate with which it will eventually be sutured as part of a triplet. As the increase of small primaries just below the radial plate is constant up to a certain age of the test, it follows that young forms have fewer small primaries than older and more conically-topped tests.

The order of the plates in a medium-sized individual appears to be as follows. The ambulacrum chosen for description is No. III. of Lovén's nomenclature (the ambulacrum immediately to the left of the madreporite, and its zones, are "*a*" and "*b*," Pl. I. fig. 5).

Taking zone "*a*" and noticing the nature of the plates from the radial plate actinally, it is found that there is the following succession (Pl. I. fig. 5):—Plates 1, 2, 3, 4 are small primaries gradually increasing in size. The plate 5, also a primary, is pushed, as it were, aborally, by the aboral expansion of the seventh plate, and just escapes being a demi-plate, for it only touches the median suture by a narrow point. Plate 6 is a demi-plate, separated from the median sutural line by the large tubercle-bearing plate 7; this small demi-plate (6) forms the shoulder of the tubercle, plate 7. Plate 8 is a low primary, and so is plate 9. Plate 10 is a primary which, were there a slightly greater expansion of the next great tubercle-bearing plate, 12, than there really is, would, like its successor plate 11, become a demi-plate. Plate 11 is a small demi-plate and forms the aboral demi-plate of a triple combination-plate. Plate 12 is the central primary of this compound tubercle-bearing plate, and plate 13 is a demi-plate. This combination of plates 11, 12, and 13 somewhat resembles those found lower down.

In zone "*b*" the first three plates near the radial plate are small primaries. Plate 4 is a demi-plate, and it is crowded out from the median line by the abactinal expansion of a small tubercle-bearing plate, 5. These two plates make up a compound plate. Plate 6 is a small primary with the part in the interporiferous area made angular and low.

This is the result of the pressure and crowding incident on the actinal expansion of the tubercle-bearing plate 5. The crowding is not sufficient to make the plate 6 a demi-plate, but it nearly does so. Plate 7 is a low primary with a granular ornamentation.

Plate 8 is a small primary with a low angular part in the inter-

poriferous area; for the expansion of plate 10 extends abactinally so as to crowd out almost the whole of it.

Plate 9, owing to the same cause, is a demi-plate; plate 10 is a large tubercle-bearing plate; plates 9 and 10 form a compound plate; plate 11 is a low primary. The three plates next in succession are a demi-plate, a large primary, and a demi-plate; and this is a perfect combination-plate and is like those at the ambitus.

There is much variety in the succession of the plates in the abactinal parts of the ambulacra of different individuals, and indeed hardly two are alike, and the age of the specimen has evidently to do with the diversity. But it is true that a careful examination of a number of specimens shows that there is order in the apparent disorderly arrangement of the plates, and that the perfect condition of the combination-plates of the ambitus is foreshadowed nearer the radial plate.

In an example of *Cœlopleurus sindensis*, nob., there is a very instructive succession of ambulacral plates near the radial end. In zone "*a*" there is a succession of primaries from nos. 1 to 8 inclusive; the first five are small and the sixth is large, narrow towards the median line. Plate 7 is a large primary, and is expanded towards the median line both adorally and aborally. Plate 8 is also a primary, and, like no. 6, it is contracted at the median line. Now these last three plates form a compound one with the sutures distinct, and there are, of course, three pairs of pores in the multiple plate (Pl. I. fig. 6). The central primary is enlarged towards the median line for a great granule, there being no great tubercles above the ambitus in this species, and the plates above and below are suffering from the pressure of the central primary, but not sufficiently to destroy their development near the median line and make them demi-plates. A little more pressure would make demi-plates of nos. 6 and 8*. The next plate to this set is 9, a small demi, a plate once a primary and which has been interfered with by the growth of the triplet immediately above. This demi is a small independent plate. No. 10 is a demi-plate and forms the first member of a large normal combination of a large primary, 11, and its adoral demi, 12. In the instance of this last set, as in all similar to it, the great develop-

* This combination is of considerable importance in a classificatory sense, as one of us will demonstrate shortly in a communication on the Diadematidæ.

ment of the central primary towards the median line removes every chance of the other plates being other than demi-plates.

In the zone "*b*" the succession is very simple until the eleventh plate, for the plate 1 is a small primary and 2 is a demi-plate, because 3 is a large primary expanding towards the median line. Plate 4 is a low primary associated with 5, a large primary, and 6, a smaller one. These three plates form a combination of small primaries with an intercalated large one; and a little more expansion of the last would have made them demi-plates, that is, it would have cut them off from the median line. 7 is a small solitary primary; and then comes a compound plate made up of 8, a small primary, 9, a large primary expanding towards the median line and not shutting out no. 8, but occluding 10, which is a demi-plate. Then follows a normal plate-combination of 11, a demi, 12, a large primary extending to the median line, and 13, a small demi.

III. *The Radial Plates.* (Plate I. Figs. 4 and 5.)

The radial plates are large and never reach to the periproct; they are broader than high, and the sides which are between the Basals are usually curved, the convexity being outwards. The sides which are free are curved, with the concavity outwards, and the adoral side is slightly incurved, there being a projection in the median line which may produce a double curvature. This adoral part is broad and its edge is thick in well-preserved specimens; and the median projection, which resembles a long narrow arched ridge with an adoral point, overhangs the centre of the edge. There are two small optic pores which penetrate the adoral margin between the internal and the external or back and front edges of the margin, so that they appear as small points on either side of, and below the end of, the projecting median ridge. The pores are separated at their exit from the lower edge of the plate by a delicate intermediate process, which is continuous with the overhanging process already described.

In some specimens the median ridge is made up by the coalescence, more or less perfect, of a series of granules. It sometimes happens that the terminal part of the ridge has been worn and weathered, and then the appearance is given of the presence of a single large external pore; but it is an illusion.

The outer surface of the radial plates is beautifully ornamented

in well-preserved specimens. On a fully developed plate there is the more or less continuous median ridge already noticed, with some separate granules, conical in shape, near the aboral point of the plate and breaking the continuity of the ridge. On either side of this median ridge are two or more raised ridges, separated by sunken or shallow grooves, placed obliquely and directed outwards and upwards to the suture between the radial and basal plates. The ridges and furrows are continuous with those of the Basals, the suture forming a marked thin line of separation. These ridges may be continuous over the radial plate, or they may be interfered with by the presence of granules along their line. A ridge is usually on the flank of the radial plate close to the side edge which is free and adoral to that edge within the Basals. This ridge, seen on both sides of the plates, need not be continuous with any structure of the Basals.

IV. *The Apical Sutures.*

These are beneath very distinct grooves between the Basals and Radials and between the Basals themselves. The grooving interferes with the continuity of the ridges and furrows but does not alter their direction.

In some specimens there is a decided fibrous appearance of the surface of the test in the vicinity of the sutures, and a more or less regular dove-tailing of the angular points of the fibres of one plate occurs with those of the other across the line of suture. This structure also occurs between the sutures of the interradial plates just at the surface of the grooves.

V. *The Obliquity of the Interradial Plates.*

This is very marked, and the transverse sutures of the interradia do not make right angles with an imaginary line passing vertically down the median area (Pl. I. fig. 2). The obliquity of the pairs of pores has been noticed, and it appears that the direction refers to the obliquity of the interradial plates, which pass, not straight across the space, but in a direction upwards and inwards. About midway between the apical system and the ambitus there is a decided obliquity of the outer third of each interradial plate, and the vertical zone of granules and small primaries close to the ambulacra is placed on this oblique part.

Further adorally, the secondary tubercles on the outside of the great tubercles are on an oblique and downward-trending part of the plates. Still lower, and on the actinal surface, the want of a transverse direction in the plates is evident, and in some specimens the plates are clearly oblique to the median line.

VI. *Recent Cœlopleuri.—Cœlopleurus Maillardi*, Mich., sp.

This very beautiful recent species has been found down to the depth of 102 fathoms in the seas to the E. of Africa, of the Philippines, Amboyna, and of the Indian archipelago.

The species was revised by A. Agassiz in 'The Revision of the Echini,' 1872–1874; and since the appearance of that great work there have been important notices of the species in the Report on the Echini of the 'Challenger' Expedition, 1881, p. 60, by the same author.

The description of *Cœlopleurus Maillardi* in the 'Revision' was not accompanied by a drawing of the test, but in the Report of the 'Challenger' Echini there are delineations of the test, the spines, the pedicellariæ, and the jaws.

The alliance of the fossil species *Cœlopleurus Forbesi*, d'Arch., and *C. Maillardi*, Mich., is very close; and the dissimilarities relate to increased height of, and the want of obliquity in, the interradial plates, the absence of regular rows of secondaries between the poriferous zones and the large interradial tubercles, and the delicate nature of the ornamentation in the apical system and median interradial line in the recent form. Agassiz mentions the structures in which there is variation in the different specimens of the recent species; and it is interesting to note that, as a rule, the variation does not link the recent and the fossil forms. Agassiz states, *op. cit.* page 63:—"The principal differences in smaller specimens consist in the proportionally greater width of the ambulacral areas, the absence or smaller number of the more prominent secondaries and miliaries, the proportionally narrower poriferous zone, the indistinctness of the S-shaped bands of the median interradial spaces, the slighter and less deep cuts, and the comparatively smaller size of the generative openings."

The recent form is not so tumid as the fossil species, and is comparatively higher, and more rounded and convex above the ambitus; there is not the conical flattening which is seen in the fossil forms. The small primary tubercles reach up in

the ambulacra close to the radial plate in both species, and there are a few secondary tubercles in the abactinal ambulacra in both species. The great tubercles are of the same type, and the pairs of pores of the triplet are wide apart and often intrude upon the flat edge of the base of a great tubercle. The interradial plates are higher than in the fossil forms, and there is no obliquity of the outer parts. The differences between the recent and fossil ambulacra being in matters of detail only, it is important to study these structures in *C. Maillardi*, and to compare them with those of the fossil species. We do not therefore propose to repeat any descriptions which can be found in the work of A. Agassiz, but to offer those new structural details which have been noticed by us.

The Ambulacral Region at the Ambitus.—In zone "*a*" of ambulacrum "IV." the fourth and fifth tubercles from the radial plate are the large ones at the ambitus; the third and the sixth are subequal and are decidedly smaller. The fourth and fifth are the largest tubercles of zone "*b*," and the third tubercle is slightly larger than that of the other zone. All the tubercles have, in this part of the ambulacrum, an expanded thin edge and almost circular base which covers nearly the whole of the compound triple plate, leaving, however, space enough for a miliary or two between the adoral edge of the fourth and the aboral edge of the fifth plate; but there is no such space between the fifth and sixth plates, for their bases almost come in contact in consequence of a slight downward projection of the bases, which just at that spot are a little more sharply curved than elsewhere.

There is also some space in the median area between these great tubercles, but only sufficient to permit of there being some miliaries and very small mammillated tubercles in a single row at the median line, and a small group of the same kind of ornamentation at the angles. It is this grouping that seems to produce the slight departure from the circle of the curvature of the bases noticed above. The shape of the tubercles is that of the fossil forms: there is a broad-based boss sloping up without any tumidity to a narrow top surmounted by a mamelon, which contrasts greatly with the dimensions of the rest, and which is surrounded by a shallow narrow groove, so that the neck of the mamelon is nearly as broad as the mamelon itself.

The largest of the tubercles in a medium-sized specimen is 4 millim. in breadth and the height is not quite 2 millim.

The three pairs of pores to these tubercles are placed in an arc, and each pair intrudes upon the base of the tubercle, and the adoral pore may almost be hidden by it. The pores are small, close, separated by a nodule, and they are surrounded by a peripodium except near the apex. They are placed obliquely, and their direction is outwards and decidedly upwards, so that the aboral pores are really worthy of the name, and this obliquity increases in the actinal great tubercle. The pairs of pores are wide apart, and the distance of the first and second pair is slightly greater than between the second and third. The first pair is placed on the aboral and outer shoulder of the tubercle, and a line drawn across the tubercle from the pair inwards would pass aborally to the groove around the mamelon. The middle pair is either on a level with the middle of the mamelon, or slightly adorally, and the lower pair is close to the lower and outer edge of the base.

Each great tubercle and the plate which it covers is really a triple combination ; and the sutures of the three plates are sometimes, but not invariably, slightly indicated as faint groove-like marks passing up the side of the boss from the adoral pores of the pairs. There is no trace of a passage of sutural lines over the top of the mamelon or its base, and it is evident that the ordinary method of union of triple plates seen in the Triplechinidæ does not occur (Pl. I. fig. 9).

On cutting through a specimen of *Cœlopleurus Maillardi* preserved in alcohol, and removing the delicate investing membrane from the inside of the test, the markings of the sutures of the triple combinations become very distinct to view (Pl. I. fig. 8). After drying, the more delicate sutural lines disappear ; but there are some media which restore the appearance for a while. It becomes evident on a most superficial examination that the composition of each of the great tubercle-bearing plates at the ambitus is almost the same as that of the fossil species. The sole difference is in the direction of the inner sutural lines of the aboral and adoral demi-plates of the compound plates. And indeed the difference is not a perfect one, for the almost vertical direction of these lines is noticed in some parts of the fossil forms. The difference is of no importance. As in the fossil species, each compound plate covered by a great tubercle consists of three plates, of which the aboral and adoral are small, do not reach the median line, and are

therefore demi-plates, whilst the central plate is a primary of great dimensions.

This central plate has a low poriferous portion, but the rest of it is greatly expanded, so that all the compound plate which is internal to the adoral and aboral demi-plates (that is nearer the median suture of the ambulacrum) belongs to it. The sutures of the demi-plates do not unite in any way. Guided by the view of the sutures of the compound plate as seen from within the test, it is not difficult to trace their line on the outside, either directly or by mapping out (fig. 8). The limitation of the aboral demi-plate to the upper and outer shoulder of the tubercle is very evident, and so is the position of the adoral demi-plate on the lower and outer shoulder of the tubercle. The parts of the plate and tubercle placed between the demi-plates, comprising the slope of the tubercle up to the mamelon, the mamelon itself, and all the rest of the tubercle towards the median line, belong to the great central primary plate of the triplet.

On referring again to the view of the test from within, it may be observed that the marking of the sutures on the inner side of the ambulacra is so distinct that the shape of the compound plates is readily drawn. The compound plate is, taking the largest as the type, high and hexagonal in shape, the aboral and adoral sides being the smallest. Four pairs of pores are in relation to the compound plate, but only three belong to it. The inner or adoral pore of each pair is at the end of a long groove, indicative of the growth of the plate. The aborally placed pair belongs to the tubercle-bearing plate above, and the transverse suture of these successive plates crosses the adoral pore of the pair. The next pair, which is the proper 1, of the triplet, is larger and is situated nearer the interradium than the pair just noticed. Pair 2 is of the same size as pair 1, and the pores are placed almost directly beneath those of the first pair but at some distance. The pair 3 has smaller pores, and they are placed on a vertical line beneath the aborally placed pair, and therefore to a certain extent nearer the median line than those of the pairs 1 and 2 (Pl. I. fig. 8). The inner suture of the aboral demi-plate is seen to pass from the adoral pore of pair no. 1, almost directly upwards, to reach the adoral pore of the last pair of the triplet in relation to the compound plate immediately above.

The corresponding inner suture of the adoral demi-plate passes from the adoral pore of the second pair towards the adoral pore of

the third pair, the line of direction being almost vertical, with, as is the case in the suture of the aboral demi-plate, a slight deviation towards the median line of the ambulacrum. Thus the sutures of the demi-plates do not unite with any from the central plate so as to cross the internal expansion of the compound plate towards the median line. Assisted by these inner sutural lines, there is no difficulty in observing that the arrangement of the plates externally which combine to form the great tubercle-bearing triplets is the same as is seen in the fossil species *Cœlopleurus Forbesi*, d'Archiac.

The aboral demi-plate comes as far as the groove at the base of the mamelon, at a spot almost directly abactinal to the mamelon. The adoral suture of the demi-plate is in contact with the poriferous part of the central primary plate.

Again, the adoral demi-plate extends towards the groove at the actinal edge of the mamelon, and its aboral suture is in contact with the adoral edge of the poriferous part of the great plate.

The suture passes inwards and very slightly aborally up the side of the boss, and it then turns adorally with a rounded angle. The aboral suture starts from the adoral pore of the pair no. 2, and the inner part of it terminates either at the adoral pore of pair 3, or at a spot nearer the median line on the transverse suture between the compound plate and the one immediately below.

There is no doubt that the poriferous zones of the ambulacra are very narrow, especially in the curved parts. The lines of the sutures between the zones and the interradia are hardly to be made out externally, but they are very distinct on the inside of the test. There is no rounding-off of the poriferous parts of the plates towards the interradia when they are seen from within, for the lines of the sutures pass direct from the aboral pore of one pair to that of the next below and above (Pl. I. fig. 8). The only exception to this is where the line of suture trends towards the interradium between the pairs 1 and 2, to meet the transverse suture of an interradial plate.

The Ambulacra between the Large Tubercles of the Ambitus and the Radial Plates.—A well-developed primary tubercle is seen close to the angle made by the pairs of pores below the radial plate, and there are generally three of the same sized tubercles and a larger one above the great tubercles. The distance between the small tubercles increases towards the radial plate, so that the

first and second are further apart than the second and third, and so on.

The ambulacra are narrow at this part, and the pores are by no means straight but in slight arcs; they are large and wide apart, and it is only in relation to the most adorally placed tubercles in this region that they assume the form of decided triplets.

The surface of the ambulacra at this part of the test is very slightly tumid, and it conforms almost to the general curvature of the test; but it is the sunken median area of the interradia that gives the appearance of unusual tumidity to the rest. The bases of the tubercles resemble those of the others lower down; the bosses are perhaps more swollen in the smaller tubercles, but the mamelon of each has its groove and is the counterpart of the others. The number of very small secondaries is slight amongst the higher tubercles, and it seems to increase suddenly between the third tubercle of one side and the fourth of the other.

The adoral pores of the pairs cling to the sides of the bases of the tubercles, especially of the larger. Near to the radial plate the pairs are very oblique and close, but the obliquity and propinquity diminish gradually.

No trace of the structure of the plates of this part of the ambulacra can be distinguished on the outer surface of the test; but the direction of the sutures can be seen inside, and it is comparable with that observable in medium-sized specimens of *Cœlopleurus Forbesi*, d'Archiac.

The following is the arrangement of the plates in ambulacrum IV. Zone "*b*":—

Plate 1, a small primary.
2, a small demi-plate.
3, a primary with an expanded inner part.
4, a small low primary.
5, a small low primary.
6, a small demi-plate.
7, a large primary with an inner expansion.
8, a small low primary.
9, a small demi-plate.
10, a large primary plate with great inner expansion.
11, a demi-plate.
12, a demi-plate.
13, a large primary with expansion.
14, a small demi-plate.

In explanation of these details, it is necessary to state that the

first tubercle-bearing compound plate is formed by the three plates at the top of the ambulacrum, of which the first is, as usual, a primary, the second is a demi, and the third, which, seen from the outside of the test, is closely connected with the tubercle, forms a considerable expansion aborally and beyond the median line of the ambulacrum. The adoral expansion is almost *nil*. The second plate has evidently commenced as a small primary, and has been prevented growing towards the median line by the peculiar expansive development of the third, which is a primary, plate. Then come two primaries in succession; they have no expansions, are low in vertical measurement, and are almost without granules on the outside of the test. A triplet follows corresponding to a tubercle-bearing plate; but the arrangement is not yet that of the compound plates at the ambitus. There is a demi-plate 6, followed adorally by a large primary 7, with the bulk of the tubercle upon it, and the plate extends to the median suture of the ambulacrum, the whole of the inner part of the compound plate belonging to it. No suture crosses this plate from the interradial edge. The next plate, 8, completes the triplet, and it is a low primary that reaches the median line with a narrow termination. It is to be distinguished externally by a minute tubercle being placed on it near the centre of the space between the second and third tubercles. The next triplet consists of plates arranged as is the case lower down, and there is an aboral and an adoral demi-plate with an intermediate expanded primary, which mainly carries the third tubercle from the apex. After this plate there is the same arrangement found as at the ambitus.

Now the triplets extend much over the vertical median line of the ambulacra; and the result is to prevent the development of tubercles side by side near the apex, where there is much pressing and crowding of plates. Hence, on examining the opposite zone of the ambulacrum, zone "*a*," from within, it is found that the following is the succession of the plates:—

Plate 1, a small primary.
2, a small primary.
3, a small primary.
4, a demi-plate.
5, a large primary.
6, a low primary.
7, a demi-plate.
8, a large primary.
9, a demi-plate.

In explanation, it is evident that the first three primaries cannot expand; but their downward growth, together with the expansion of the fifth plate, prevented plate 4 from being anything else than a demi. The expansion of plate 5 was not much adorally; and the consequence was that plate 6 did not suffer pressure enough to form a demi, and it remained a primary; suffering, however, from direct pressure from above downwards, and being prevented from increasing in a vertical direction, it became a low plate.

The Peristomial Region of the Ambulacra.—The plates and the tubercles become smaller and closer towards the peristome, and yet, although the plates are lower and narrower from side to side, there is no doubling of the pairs of pores. These are in a series of simple arcs close to the edge of the tubercles, and, except at the lowest of all the tubercles, the arrangement of the pairs resembles that seen higher up the test. There is a little crowding of the lowest triplet, and the first pair of it may be rather more externally placed than is usual elsewhere. As a rule, the arrangement is rather more simple than that seen in the fossil species.

Just outside the poriferous zones is a long and narrow plain "tag," and it reaches from the small branchial cut and ends in a point at some distance aborally. The plain construction of this tag is in marked contrast with the arcs of broadly elliptical peripodia which support the triplets of pairs of pores close by. We do not enter into the consideration of the function of the tag, as it will be treated of by one of us on a future occasion.

The suturing of the plates of the peristomial triplets is on the same plan as that of the compound plates of the ambitus; the demi-plates are lower and broader, however, but they are placed in the same positions relatively to the great primary plate as in the ambital regions.

The auricles are small, disconnected, and there is no union by a raised plate crossing the interradia.

At the peristomial end of the ambulacra, the deep pits for the sphæridia are very prominent objects in the line of the median suture and at those places where it is joined by the transverse sutures. When the ambulacral plates of either side are separated, so as to divide the sphæridial pits along the median line, the separated faces of the median suture show deep sphæridial

pits and intervening projections; but, as A. Agassiz has noticed, there is no structure at that spot like that of the Temnopleuridæ.

VII. *The Interradial Plates and their Sutures.*

The interradial plates which succeed the small ones immediately around the apical system are remarkably high and broad, and thus they differ from those of all the fossil species. The slight development of secondary tubercles between the great primary tubercles of the interradia and the poriferous zone of the ambulacra, appears to prevent that breadth and obliquity of the plates which is seen in the fossil forms. The great tubercles are of the same shape as those of the ambulacra; and when the inside of the test is examined, the surface beneath them is seen to be hollowed.

The suturing of the plates together is excessively close; and in the specimen which one of us has prepared for the National Collection, and which had been kept in alcohol, the test often broke across the plates themselves instead of at the sutural lines.

The transverse sutures between the interradial plates separated much more readily than those of the vertical or median zigzag line. Any separation along these median sutures is hard to get, and there is an evident and very interesting reason.

On the adoral suture of every interradial coronal plate there is a series of knobs, and these prominences of the tissue of the plates are either hemispherical or elongated. There are also small pits placed here and there, between the knobs, and the whole surface of the sutural face is somewhat swollen (Pl. I. figs. 11 & 12).

On the aboral faces of the sutures, on the contrary, there is a series of depressions resembling pits or elongate holes, and the presence of a few knobs in the midst is evident.

This arrangement of the adoral and aboral faces of the sutures resembles, to a certain extent, the dowelling of *Temnopleurus*, described by one of us in a former communication to the Society, but the knob-and-socket structure is not so perfect*. It is evident that the knobs and elongate processes fit into the sockets and holes of the face of the plate which is opposed to them.

* Journ. Linn. Soc. vol. xvi. p. 343 (1881).

The transverse sutures of the interradial coronal plates near the apex are well marked with knobs on one side and with pits on the other. The dowelling is as complete as in any Temnopleurid. But lower down and near the ambitus, the sutural arrangement ceases. We have not been able to see this knob-and-socket structure in the ambulacra, for we have not been able to sacrifice an ambulacral area on purpose.

The adoral faces of a basal plate and of the contiguous radial plate are covered with knobs; but it does not appear that this is universal, for whilst in some interradia the adoral faces of the transverse sutures of the plates close to the apex are knobbed, others have sockets.

VIII. *The Radial Plates.*

On carefully denuding one of the radial plates of the specimen preserved in alcohol, the structure of the adoral edge of the plate was rendered visible. The adoral margin of the plate is not a perfect arc, for there is a protuberance in the median line which has a triangular piece underneath it, the outer edges of which are in contact with the aboral margins of the first poriferous plates of the ambulacrum. The protrusion has a broad base, adoral to a glassy tubercle, and there is a narrow and long process in the median line which, with the triangular piece, forms the centre of the adoral margin of the plate. A very minute optic pore is seen on either side of the central process, close to the free edge of the plate. When the radial plate is examined from within, there appears a deep pit close to the adoral edge, and it is evident that the nerve divides and that, as in the fossil forms, there are two optic pores which open obliquely, and do not appear on the outer or coloured surface, but on the adoral edge of the plate. The pores look downwards, or adorally and slightly outwards.

The specimens show faint ridges and furrows on the radial plates, crossing to them from the Basals, and interfered with to a certain extent by the baso-radial sutures. A low ridge is also in the median line, and the knob alluded to terminates it.

Genus Arbacia, *Gray.*

IX. *Structure of the Ambulacral Plates.*

In *Arbacia*, Gray, the ambulacral plates, except in the neigh-

bourhood of the apex, are compound plates as in the Triplechinidæ, that is to say, each is built up of several poriferous plates. The grouping of these plates and their relations *inter se* are, however, very different in the forms under notice and the group to which we have just referred.

In most of the species of *Arbacia* (e.g. *A. stellata*, *A. punctulata*, *A. pustulosa*) there are three poriferous plates in each compound ambulacral plate. The adoral and aboral plates of this triplet are small demi-plates, and occupy scarcely more than half the length of the ad- and aboral margins of the compound ambulacral plate respectively; and the mean depth of these plates may be roughly stated as being about one third of the depth of the whole compound ambulacral plate. It thus follows that the greater part of the compound ambulacral plate (approximately two thirds) is formed of one large primary poriferous plate, which occupies the whole of the inner half of the compound plate, and which also extends as a narrow strip between the two small demi-plates above mentioned, its outline being more or less spade-shaped, or fancifully suggestive of an old-fashioned sugar-spoon.

The forms and posture of these plates differ more or less in the different species of *Arbacia*. After the preliminary remark that the compound plates may be best studied at a little distance above the ambitus, and from thence to the peristome, we proceed to examine *Arbacia pustulosa*.

In this species the whole ambulacral plate is subject to a more or less considerable adoral flexure at the commencement of the poriferous region, which will be seen on referring to fig. 1 (Pl. II.). The aboral poriferous plate, which is a demi-plate, has a rounded extremity internally; the suture commences almost at a right angle to the aboral margin of the whole ambulacral plate, mounts the boss of the primary tubercle, curving meanwhile, and the bend being completed near the summit of the boss, the suture thence proceeds in a direct but inclined line to the outer end of the compound plate. The aboral demi-plate is somewhat enlarged at its outer end, as shown in the figure. The adoral demi-plate, on the other hand, is enlarged at its internal end, and in consequence presents somewhat of a pyriform outline; its suture mounts the base of the boss of the primary tubercle, is rather rapidly bent with a well-rounded curve until at a right angle to its initial direction, and thence proceeds in a slightly sigmoid

curve up to the outer end of the plate. Consequent on the forms of the two small demi poriferous plates above described, the intermediate portion or prolongation of the large primary poriferous plate is inclined at an angle adorally, and its outer end is slightly enlarged (see fig. 1). The enlargements of the three plates above referred to correspond to the position of the relatively large, suboval or palette-shaped peripodia.

At a few plates above the ambitus the three peripodia with their pairs of pores form an almost vertical, and very slightly curved, arc; at the ambitus the curvature of the arc is more definite; and below that position the peripodium of the adoral demi-plate is seen to have assumed a much more internal position in relation to the other peripodia of the compound ambulacral plate to which it belongs. (Fig. 1 represents the fifth and sixth tubercle-bearing plates, counting from the peristome.) This apparent moving inwards of the adoral peripodium, away from the outer end of the plate, is continued in each succeeding ambulacral plate down to the peristome. Below the ambitus the peripodium of the aboral demi-plate also moves slightly inwards, away from the outer margin of the ambulacral plate, but to a much less degree. The peripodia as they approach the mouth maintain with but very slight diminution their uniform size; the plates, however, upon which they are borne, in the four or five ambulacral plates next to the peristome, decrease successively in depth and become mere band-like strips. Consequent on this and the inward movement of the pores above referred to, the crowded and almost transverse arrangement of the peripodia near the peristome is produced. When a suitable preparation is examined under the microscope, it is found that although the two or three ambulacral plates next the peristome have more or less lost their superficial individuality, the constituent poriferous plates are still distinguishable as independent band-like strips occupying their original relative position, and that the peripodia are expanded, and poured over superficially as it were, occupying an area whose diameter is much greater than the mean depth of the plate to which they belong. Figs. 4 and 5 illustrate these observations in another species; and a comparison of the two will at once indicate how the crowded mass of peripodia near the peristome may be reduced to order, in conformity with their disposition at the ambitus. It will be readily observed that the more or less regular arrangement in obliquely transverse lines

or arcs is in reality a secondary formation caused by the movement of the peripodia and the modification of the plates above noticed. It may be conjectured that the two more adoral poriferous plates of the first compound ambulacral plate have been resorbed or merged in the peristomial rim, and that the peripodium of the aboral demi-plate alone remains, its adoral foramen notching the peristome. The peripodium of the adoral demi-plate of the second ambulacral plate is also very near the margin, and may be said to partially notch it. The growth stages upon which this merging and obliteration of plates depend have been carefully described by Lovén (*op. cit.*) in the case of *Strongylocentrotus drœbachiensis*, and need not be recapitulated here.

In *A. stellata* the same general arrangement and relative proportions of the poriferous plates in the ambulacral compound as those above described occur. The outline, however, of the plates is different (see fig. 5). It will be observed that the small ad- and aboral poriferous plates—the demi-plates—of the triplet have a straight or truncate inner end, parallel to the outer line of the ambulacral area, the suture-line mounting the base of the boss at a right angle to the ad- and aboral margins of the compound ambulacral plate respectively, and is then sharply bent, forming an angle less than a right angle, to direct its course towards the outer margin of the ambulacral area. The outline of the demi-plates is thus more or less trapezoid, and their greatest depth is at their inner end. In consequence of this the intermediate portion of the main primary poriferous plate is somewhat cuneiform, expanding as the margin of the ambulacral area is approached, where its greatest depth is situated. The same narrowing of the plates in the neighbourhood of the peristome takes place as already noticed in *A. pustulosa*, and the peripodia in consequence become crowded (see fig. 4). Their arrangement may be readily formulated by comparing them with fig. 5.

In *A. punctulata* the ambulacral structure approaches in character very closely to that of *A. stellata*, as reference to fig. 2 will suffice to show.

The manner in which the ternary compound ambulacral plates, with which we are now concerned, are formed, may be well studied on the upper portions of the ambulacral areas of any of the species of *Arbacia* above mentioned; and their development is highly instructive. In the neighbourhood of the apical disk

(see Pl. II. fig. 3) all the poriferous plates are simple and entire —that is to say, primary plates which extend from the median suture of the area to its outer margin, each with a single pair of pores. At a very short distance from the apex—on the fifth or seventh plate from the radial (ocular) plate in the case of *A. stellata*—there is an unmistakable tendency to form binary compound plates, which manifests itself in the greater increase of the plate in question than in its immediate neighbours of the same column. This enlargement of the plate takes place at its inward end, in such a way as to environ the whole of the inner end of the next aboral poriferous plate, thus intercepting the entry of that plate into the median suture, and preventing its further growth in that direction, causing it to remain a small or demi-plate henceforward. It may also be seen that one, or sometimes two, simple primary plates intervene between each of the succeeding binary compounds thus formed. These ultimately become the adoral small or demi-plates of the ternary compounds, consequent on an adoral encroachment of the main primary poriferous plate, similar to its aboral increase just noted. It will further be observed that the increased primary poriferous plate in one column of the ambulacrum is opposite to a small poriferous plate in the adjacent column, the growth of which it appears to have prevented, and thus perhaps determines the reason why the small primary plate (at this period still an entire one) which underlies, or is adoral to, the binary compound plate in the adjacent column, ultimately becomes the adoral member or small demi-plate in the mature ternary compound. This alternate increase and debarred growth is necessarily reciprocal in the two columns. It is not till near the ambitus that the true fully-formed ternary compounds, previously described, are met with. In a small test with a diameter of 33 millim., the 23rd, 24th, and 25th poriferous plates constitute the first true typical ternary compound ambulacral plate; though, critically considered, the two preceding triplets might essentially be almost ranked as such.

In *A. punctulata* the first true ternary compound ambulacral plates are as near to the ambitus as in *A. stellata*; the 23rd, 24th, and 25th primary poriferous plates, or even the 26th, 27th, and 28th from the apex, constituting the first typical triplet.

In *A. pustulosa* the ternary plates have the appearance of being somewhat further removed from the ambitus, for although when counted from the apex the position of the first typical triplet

corresponds numerically with that in *A. stellata* and *A. punctulata*, several of the preceding series form distinct incipient triplets.

It is especially interesting to note how closely the two species *Arbacia stellata* and *A. punctulata* resemble *Cœlopleurus* in their ambulacral structure, even to the trapezoid form of the small or demi poriferous plates ; and the significance of the fact is further enhanced when it is remembered that these two species of *Arbacia* approach *Cœlopleurus* much nearer in general character and habit than does *A. pustulosa.* The same remark also applies to *A. spatuligera* and *A. Dufresnii*, the ambulacral structures of which conform so closely to what has been above described, that reference in detail is unnecessary for the present purpose. It is probable that *A. alternans*, Troschel, will stand in the same category, if indeed the species is really an independent one.

X. *Ambulacra of* Arbacia nigra.

In concluding these notes on the ambulacra of *Arbacia*, we would remark that the form known as *A. nigra* presents an altogether different structure from that of the group of species we have been discussing. The compound ambulacral plates in this species are composed of four or five poriferous plates, and it will be seen on reference to fig. 6 that it is the lowest or adoral poriferous plate which is the main primary and occupies the greater portion of the compound plate, the other poriferous plates being all small or demi plates, the main primary plate mounting up and occupying nearly a third of the aboral margin of the compound ambulacral plate. This arrangement, whilst recalling that of some Triplechinidæ, has at the same time a definite character of its own. This difference of structure in our opinion removes *A. nigra* from the genus *Arbacia*—a question to which we shall refer in Part II. of this paper.

XI. *Structure of the Vertical Sutures of the Interradia.*

A noteworthy system of dovetailing or "dowelling" occurs in the median interradial suture of the coronal plates in *Arbacia.* This consists of a series of knobs or eminences situated on the adoral facet of the inner end of the interradial plates, and these fit into corresponding sockets or pits on the aboral facet of the adjacent plates in the neighbouring column. Each coronal plate has consequently knobs on its adoral facet and pits on its aboral

facet. These structures recall, more or less vividly, the system of dowelling by knobs and sockets, previously described by one of us in Temnopleuridæ *; in the case of *Arbacia*, however, they are confined to the vertical sutures entirely, no trace whatever of their existence being found on the horizontal sutures which separate the successive plates in a column: or in any case only a slight granular surface, presenting, on separation, a faintly carious appearance.

The special form of the knobs and pits varies in the different species that we have examined, and would appear to constitute a good secondary specific character; it also varies a little, but in a definite manner, according to the position of the plate upon which it occurs—in other words, the dowelling on the abactinal surface is slightly different from that on the actinal surface. This structure appears to exhibit its maximum development on the abactinal surface about midway between the ambitus and the apex.

On examining the seventh interradial plate (counting from the apex) of *A. stellata*, a number of small round semiglobular prominences will be seen forming more or less regularly three lineal series, which occupy about half the area of the facet. The eminences and pits on the respective facets are confined to a well-defined area, between which and the edges of the facet that correspond to the internal and external surfaces of the plate respectively a straight smooth margin intervenes; the knobbed and pitted area being rather nearer to the internal than the external surface of the plate (see fig. 7). Nearer the ambitus the granular knobs are more numerous and less regular in their disposition.

In *A. punctulata*, on the seventh plate from the apex, instead of the semiglobular rounded knobs found in *A. stellata*, we have a series of larger and more elongate prominences, either oblique in position or subparallel with the lateral sides of the facet, the individual prominences becoming narrower and suboval in contour as they approach the end of the facet adjacent to the aboral facet of their own plate (see fig. 8). Roughly speaking, they may be said to form only a single series (though there is a slight tendency to double in the part where the smaller-sized knobs just mentioned occur); and the area they occupy is narrower than the area occupied by the knobs in *A. stellata*.

* P. Martin Duncan, Linn. Soc. Journ., Zool., vol. xvi. pp. 343–358.

On the plates at the ambitus and below, these broad prominences become broken up into rounded knobs, very like the structure in *A. stellata*, although they do not appear to form more than two series, and generally one or more of the broader "uniserial" prominences remain.

The plates of the apical system are united together by a dowelling of numerous small semiglobular knobs, less regular in their disposition than any of the foregoing; the basal (genital) plates bearing only knobs, whilst the radial (ocular) plates bear pits only.

In *Tetrapygus* (*Arbacia*) *nigra* the sutural dovetailing is very remarkable, and highly developed. On the seventh plate from the apex, it consists of a single series of large, broad, subtriangular, plate-like prominences arranged transversely on the surface of the facet, and slightly inclined aborally in relation to its plane (see fig. 9). As the plates approach the ambitus, the plate-like prominences gradually become broken up into rounded elongate prominences, one half of the plate-like form remaining, whilst the other is formed as it were into the smaller, but equally long, prominences. Below the ambitus, on the actinal surface, the breaking up is still further carried out, and we find a number of small granule-like knobs arranged in wavy lines across the plate, amongst which some apparent confluence is visible.

In all these cases, the aboral facet of the adjacent plate in the neighbouring column of the interradium to which the knobbed facet is apposed, is furnished with exactly correspondent depressions or pits, into which the prominences fit.

In the species we have been discussing, there is a similar system of dowelling, but less developed, at the junction of the ambulacral plates and the interradial plates, here present in the form of small uniform rounded granule-like knobs; and the knobs are all borne on the ambulacral plates, whilst the adjacent end of the interradial plates bears only pits.

There is also a similar system of dowelling in the vertical or median zigzag suture of the ambulacral area, the knobs being borne on the aboral facet of the plate, whilst the pits are borne on the adoral facet, the reverse of what takes place in the median interradial suture. The dowelling in the median ambulacral suture is comparatively feebly developed, and resembles that between the ambulacral and the interradial plates, having, in some instances, at first sight little more than a "carious" appearance.

Radial Plates.—These are upon the same plan as those of *Cœlopleurus*, and as the peculiar central ridge and the position of the two optic pores have been described by Lovén (*op. cit.* pp. 66 and 67), it is not necessary to do more than refer to that careful naturalist's descriptions.

XII. *Comparison between the two Genera.*

It is evident from the descriptions given of the ambulacra, radial plates, and interradia of the fossil and recent species of the genus *Cœlopleurus* and of the species of *Arbacia*, that these forms have a great similarity of structure. In all, with the exception of *Arbacia nigra*, the compound plates of the ambulacra are formed of an adoral and an aboral demi-plate with a large central primary plate.

In all the forms the optic pores are double, and the perforation is in the adoral edge of the plate, a process separating the pores. In all the forms the median or vertical sutures of the interradia are marked with knobs or ridges, which correspond with sockets or short grooves on the opposed plate-edges. This kind of dowelling is even seen in the ambulacra of *Arbacia* and along the transverse interradial sutural edges of *Cœlopleurus*.

Arbacia nigra is an exceptional species, and, as will be shown in Part II. of this communication, belongs to a different genus from the *Arbacia*.

It is of importance to remember that *Cœlopleurus* was the first of the two genera, and that there were species with the peculiar ambulacra in the Eocene, Oligocene, and Miocene; that the recent species from the Indian seas only differs from the Miocene form in having high and not oblique interradial plates; and that all the species of *Arbacia* which were examined, except one which other authors have eliminated, present no greater differences than can be accounted for on the theory of descent. The *Arbaciæ* are recent forms.

DESCRIPTION OF THE PLATES.

Plate I.

Fig. 1. *Strongylocentrotus dræbachiensis.* A compound ambulacral plate from a young example. *a'*, the aboral primary poriferous plate; *a''*, the adoral primary; *b*, the intermediate demi-plate. Magnified.

2. *Cœlopleurus Pratti.* Compound ambulacral plates and adjacent interradial plates from the region of the ambitus. Magnified.

Fig. 3. *Cœlopleurus equis.* A compound ambulacral plate from the region of the ambitus. *a*, the large primary poriferous plate; *b'*, the aboral demi-plate; *b''*, the adoral demi-plate. Magnified.

4. *Cœlopleurus sindensis.* Radial plate and neighbouring abactinal region of the ambulacrum. Magnified.

5. Radial plate and abactinal portion of the ambulacrum, to show the manner of the formation of the compound ambulacral plates. Magnified.

*6. An incipient compound ambulacral plate, formed of the 6th, 7th, and 8th primary poriferous plates. Magnified.

7. *Cœlopleurus Maillardi.* An ambulacral plate near the peristome, showing the broad plates and a spheridial pit. Magnified.

8. Portion of the ambulacrum IV., seen from within. Magnified.

*9. One of the large tubercles. Magnified.

10. Arrangement of the peripodia at the peristome. Magnified.

11. The end of an interradial plate, in the median suture, showing the knobs and pits. Magnified.

12. The corresponding facets of the two adjacent plates in the neighbouring column, furnished with reciprocal pits and knobs, into which those of the plate shown in fig. 11 fit.

Plate II.

Fig. 1. *Arbacia pustulosa.* Compound ambulacral plates from the region of the ambitus. *a*, the large primary poriferous plate; *b'*, the aboral demi-plate; *b''*, the adoral demi-plate. Magnified.

2. *Arbacia punctulata.* A compound ambulacral plate from the region of the ambitus. Magnified. The same lettering as the above.

3. *Arbacia stellata.* Radial plate and abactinal portion of the ambulacrum IV., to show the manner of the formation of the compound ambulacral plates. Magnified.

4. Portion of an ambulacrum and adjacent interradial area near the peristome, to show the arrangement of the peripodia. Magnified.

5. The same, showing the constitution of the compound ambulacral plates. Magnified.

6. *Tetrapygus* (*Arbacia*) *nigra.* A compound ambulacral plate. *a'*, the primary poriferous plate; *b'*, *b''*, *b'''*, the demi-plates. Magnified.

7. *Arbacia stellata.* The end of the 7th interradial plate from the apex in the median suture. The adoral facets with knobs only, the aboral with pits. Magnified.

8. *Arbacia punctulata.* The end of the 7th interradial plate from the apex in the median suture. Magnified.

9. *Tetrapygus* (*Arbacia*) *nigra.* The end of the 7th interradial plate from the apex in the median suture. Magnified.

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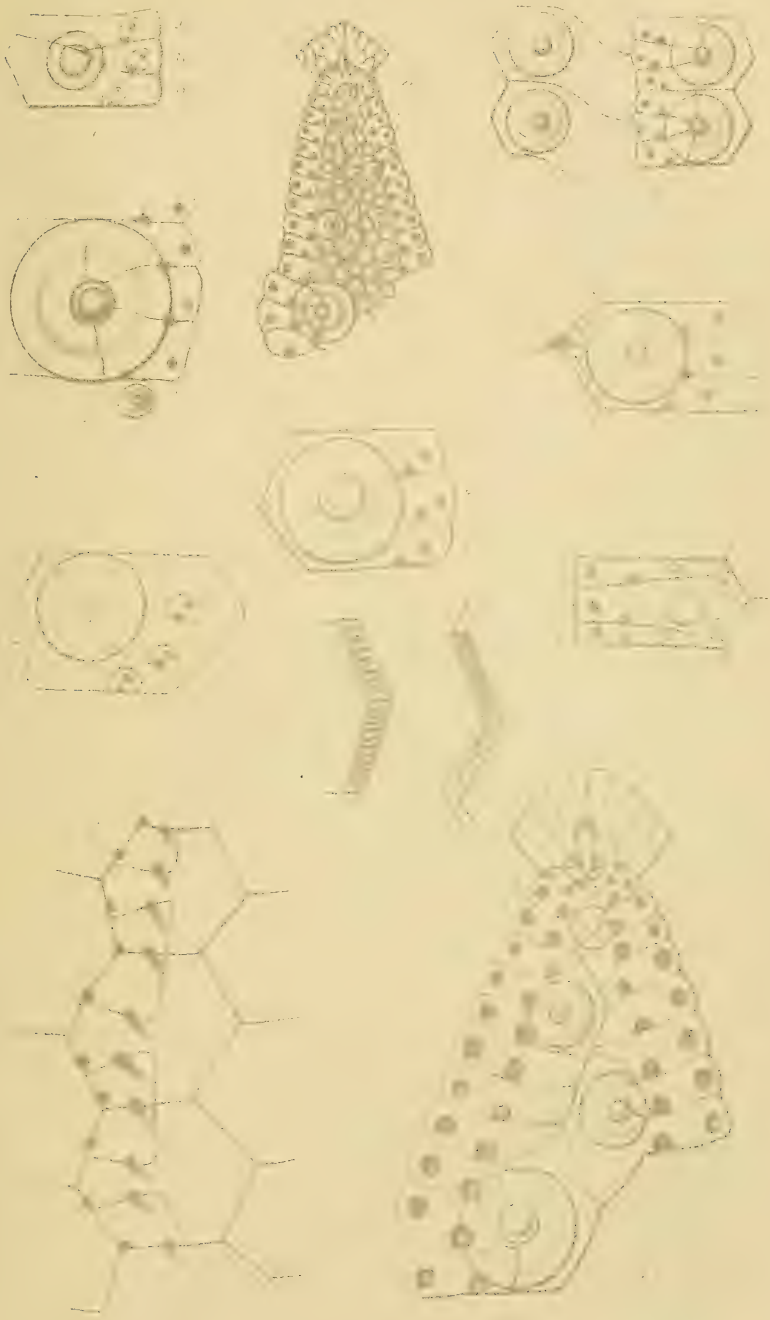
* In the lettering of Plate I. the numbers to figs. 6 and 9 have been inadvertently misplaced, and should be transposed.



Berjeau lith. STRUCTURE OF APRACIA Hanhart imp.